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SUMMARY

Superboom measurements and calculated pressure patterns have been made for fighter aircraft in level accelerated flight and in turn maneuvers. A summary of the main findings of these superboom studies, qualitative comparisons with analysis, and a physical explanation of some of the observed phenomena are presented.

From 2 to 6 booms were observed (compared with the normally observed 2 booms for steady flight), and pressure-buildup factors of from 2 to 4 were measured (depending on the type of maneuver and the location of the observer). The relative positions of the multiple shocks were predicted within 1,000 feet, and the location of the initial superboom impact was found to be predictable within about ±2 miles when the temperature profile and airplane position information were available.

INTRODUCTION

The sonic boom is recognized as an important operating problem with regard to possible adverse community reaction to military supersonic training operations and future SCAT operations (see refs. 1 and 2). Several analytical studies are available which indicate that the sonic-boom intensity at ground level may be significantly affected by the manner in which the aircraft is operated (refs. 3 to 6). In particular, certain maneuvers of the aircraft in which either longitudinal or lateral accelerations occur can result in so-called "superbooms." The superboom phenomenon is illustrated in figure 1 which shows the shock-wave-intersection patterns for two flight conditions of an aircraft. For simplicity, only the bow shock wave is shown.

At the left of figure 1 the lateral spread pattern on the ground for an aircraft in steady flight is shown. The projections of the ray paths on the ground, as represented by the fine lines, are generally parallel to each other; and the shock-wave ground-intersection pattern, as represented by the heavy line, is essentially hyperbolic in shape. The pattern at the right is for an aircraft experiencing a lateral acceleration (see ref. 6). The ray paths are no longer parallel; in fact, in some regions they tend to converge and in others to

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diverge. Likewise, the shock-wave ground-intersection pattern is no longer hyperbolic and may contain some irregularities and cusp formations in which the pressures are higher than for the steady flight condition. Such pressure buildups are referred to as "superbooms," and while they may be several times as large as the corresponding steady-flight booms, they need not be large on an absolute basis.

SOURCES OF SUPERBOOMS

These superboom conditions may occur over small localized areas on the ground during any accelerated portion of the flight of the aircraft. There are several phenomena that are believed to cause superbooms. The first of these phenomena is a change in flight-path geometry in which the aircraft experiences a lateral acceleration. Examples of lateral accelerations are the sideslip maneuvers (as illustrated in the right-hand portion of fig. 1), constant-speed turns, and pushover-dive-pullout maneuvers. Another source of superbooms is a longitudinal acceleration that might occur as speed is increased from subsonic

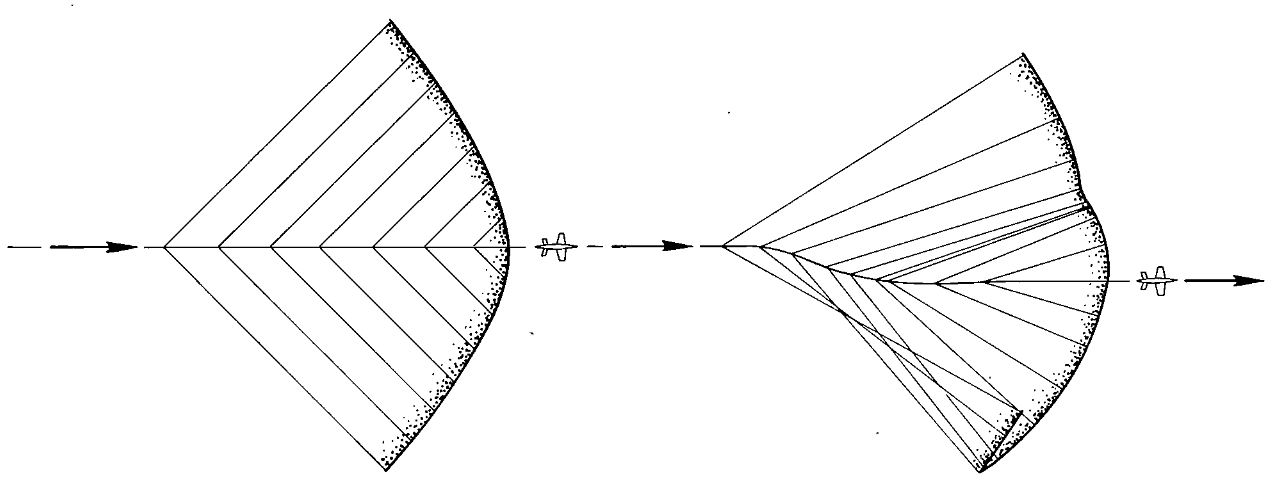

Figure 1.- Shock-wave ground-intersection patterns for aircraft in steady and accelerated flight at constant altitude.

to low supersonic in the cutoff Mach number range; that is, the Mach number range in which the shock waves from the aircraft first reach the ground. It is also believed that superbooms may result from atmospheric focusing of the ray paths due to certain temperature and wind-gradient conditions and turbulence (see refs. 7 and 8). Of course, all of these phenomena may be in operation at the same time during the flight of an aircraft, and thus a rather complex superboom-generating condition might exist. Only fragmentary experimental data are presently available to verify these theoretical concepts (see ref. 9). A series of experiments, therefore, has been conducted under carefully controlled conditions in order to confirm the existence of the predicted ground-pressure distributions and to study the effects of the previous variables believed to cause superbooms (ref. 10). The main objectives of the present paper are to summarize the main findings of these superboom studies, to make qualitative comparisons with available theory, and to give a physical explanation of some of the observed phenomena.

TEST ARRANGEMENTS

The area in which the tests were conducted and the arrangement of the test facilities and equipment are shown in figure 2. Flights were made in the

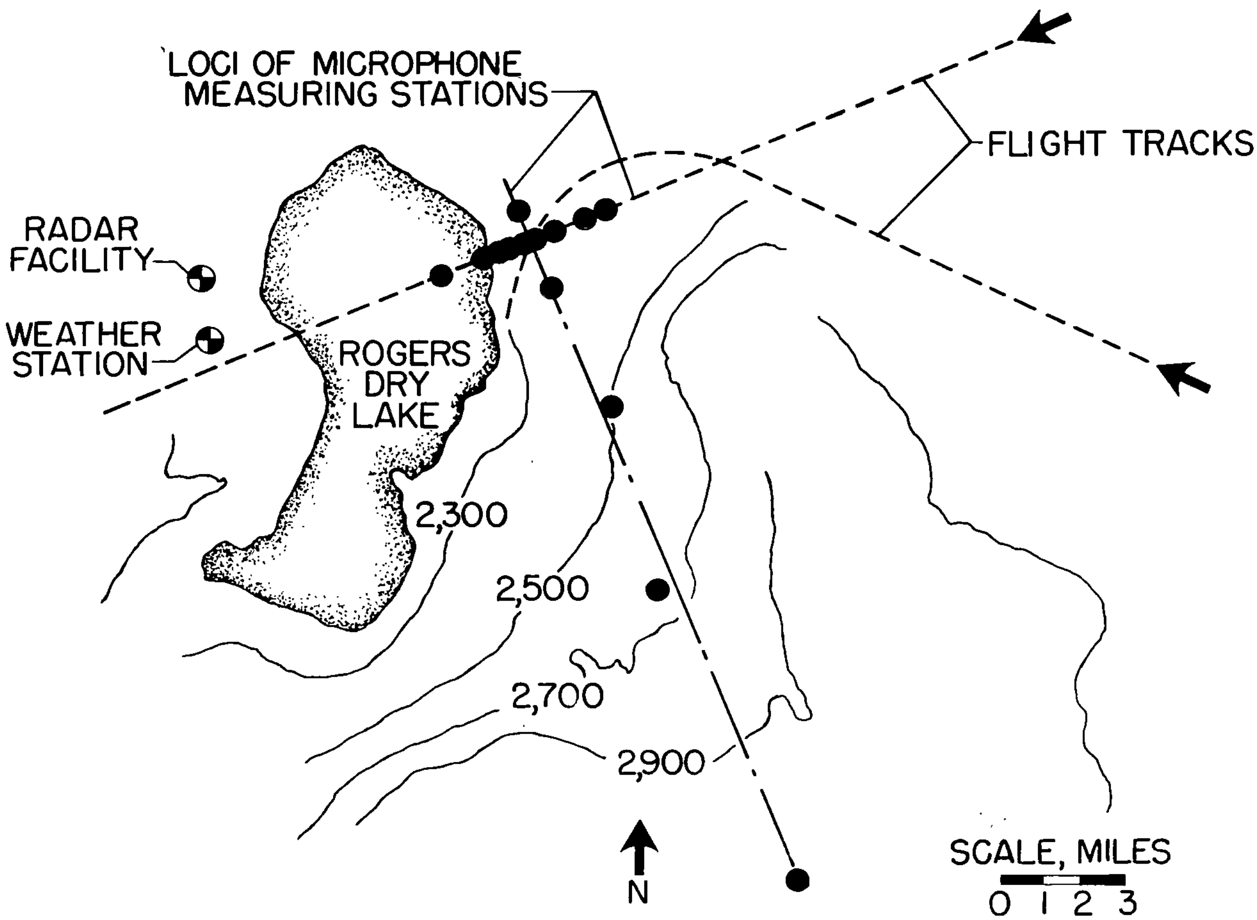

Figure 2.- Arrangement of test facilities and equipment.

vicinity of Edwards Air Force Base, California, during September and October of 1961 as part of a joint National Aeronautics and Space Administration-Air Force-Federal Aviation Agency sonic-boom research program. Since the area was generally flat as suggested by the contouring, it was believed that possible effects of terrain were minimized. Microphones were located in the vicinity of

Rogers Dry Lake and were arranged in a T-shaped array having the approximate dimensions 4 miles by 20 miles, as indicated by the solid symbols in the figure. The aircraft was directed on course and was tracked accurately by means of the radar facility. Prior to each test flight conventional rawinsonde weather observations were obtained at 1,000-foot intervals up to altitudes exceeding the flight altitude. As an example of the manner in which the tests were conducted, two planview flight paths are indicated in the figure. One of these was used for constant-altitude longitudinal accelerations and pushover-dive-pullout maneuvers, and the other was used for constant-speed circular turns at constant altitude.

GROUND-PRESSURE MEASUREMENTS

The type of data recorded during the longitudinal-acceleration runs is presented in figure 3. At the top of the figure is a schematic diagram illustrating a profile view of the ray paths for this maneuver. For convenience, the diagram has been foreshortened. Reading left to right, the airplane has accelerated to a low-supersonic Mach number at a constant altitude of 14,000 feet. The flight was conducted in such a way that the ray paths associated with this critical Mach number range intersected the ground-test area (as illustrated by the heavy line) where a large number of microphones were arrayed (see fig. 2). Sample shock-wave—pressure time histories obtained at three locations in the ground-pressure field are presented at the bottom of figure 3. The pressure recording at position (a) consisted essentially of a single, very strong N-wave (so called from the shape of the signature). At position (b) two complete N-waves were recorded, and these were separated by a short-time interval. At position (c) two N-waves were also recorded, but here the time interval between them was relatively longer. It can be seen from a study of the ray-path diagram that a definite progression exists. The pressure signature measured at point (a) is believed due to a series of disturbances along the segment A_1A_2 of the flight path. The speed of the airplane and the lengths of the ray paths were such that the disturbances reached point (a) at essentially the same time, and were hence in phase. This resulted in an overpressure value approximately

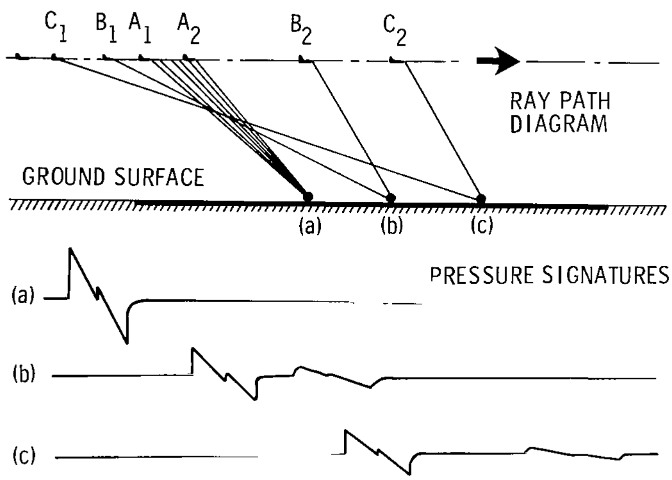

Figure 3.- Measured pressure signatures at three ground stations along with ray-path schematic diagram for a longitudinal acceleration of an aircraft from Mach number 0.98 to 1.2 and a constant altitude of 14,000 feet.

twice as great as the maximum overpressure measured along the ground track at any of the other locations. By definition, such a condition of pressure enhancement is considered a superboom condition.

Ray paths from points B_1 and B_2 both intersect the ground at point (b). In this case, the speed of the airplane and the length of the ray paths were such that these disturbances did not arrive at the same time, as illustrated by the measured pressure time history at point (b). The disturbance from point B_2 traveled the shorter distance, arrived sooner at point (b), and had a higher overpressure than the disturbance from point B_1. At point (c) the same phenomena occurred. The overpressure of the initial N-wave signature was comparable to the initial N-wave signature measured at point (b). The second signature, however, had traveled a considerably longer distance, arrived at a later time, and had a relatively lower overpressure.

Figure 4 provides a clear picture of the shock-wave formation on the ground for the same longitudinal-acceleration maneuver. This figure presents a perspective-view sketch of the shock-wave patterns rather than a profile view of the ray-path patterns. To simplify the picture further, only the bow-wave shock patterns are shown on one side of the ground track. In this figure the relative position of the first and second N-wave disturbances in the vicinity of points (b) and (c) can be seen. Because these disturbances are displaced, they arrive at different times as indicated by the pressure traces shown at the bottom of the figure. As a matter of interest, it can be seen that the cusp formations may exist at various lateral distances from the ground track, and, although no measurements were made, superbooms may be observed in these areas.

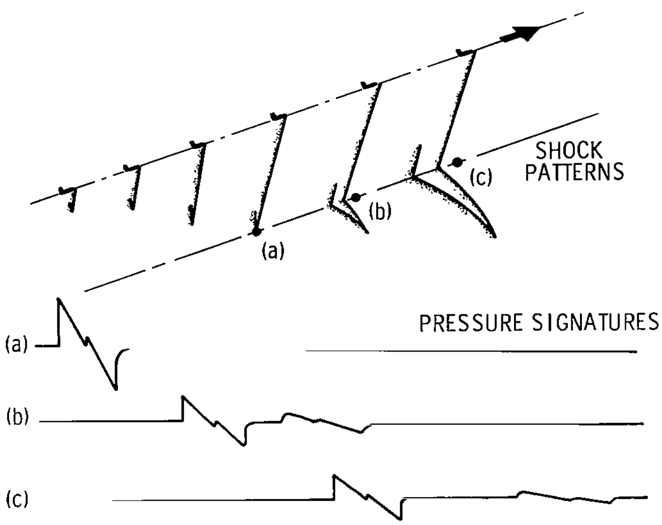

Figure 4.- Measured pressure signatures at three ground stations along with shock-wave schematic diagram for a longitudinal acceleration of an aircraft from Mach number 0.98 to 1.2 and a constant altitude of 14,000 feet.

Data similar to those discussed in figure 4 for a longitudinal acceleration were also obtained for several lateral accelerations in which the aircraft was flown in constant-speed circular turns over the same instrument array. Calculated ground-shock patterns for a circular turn for a Mach number of 1.5 at an altitude of 32,000 feet are presented at the top of figure 5. For convenience, only the more interesting part of the shock patterns, which in this case occurs near the ground track, is shown. A rather complex bow-wave pattern is observed in the test area. This pattern is unsymmetrical about the aircraft ground track, and from 2 to 6 booms were measured, depending on the location of the equipment. As an illustration of the type of

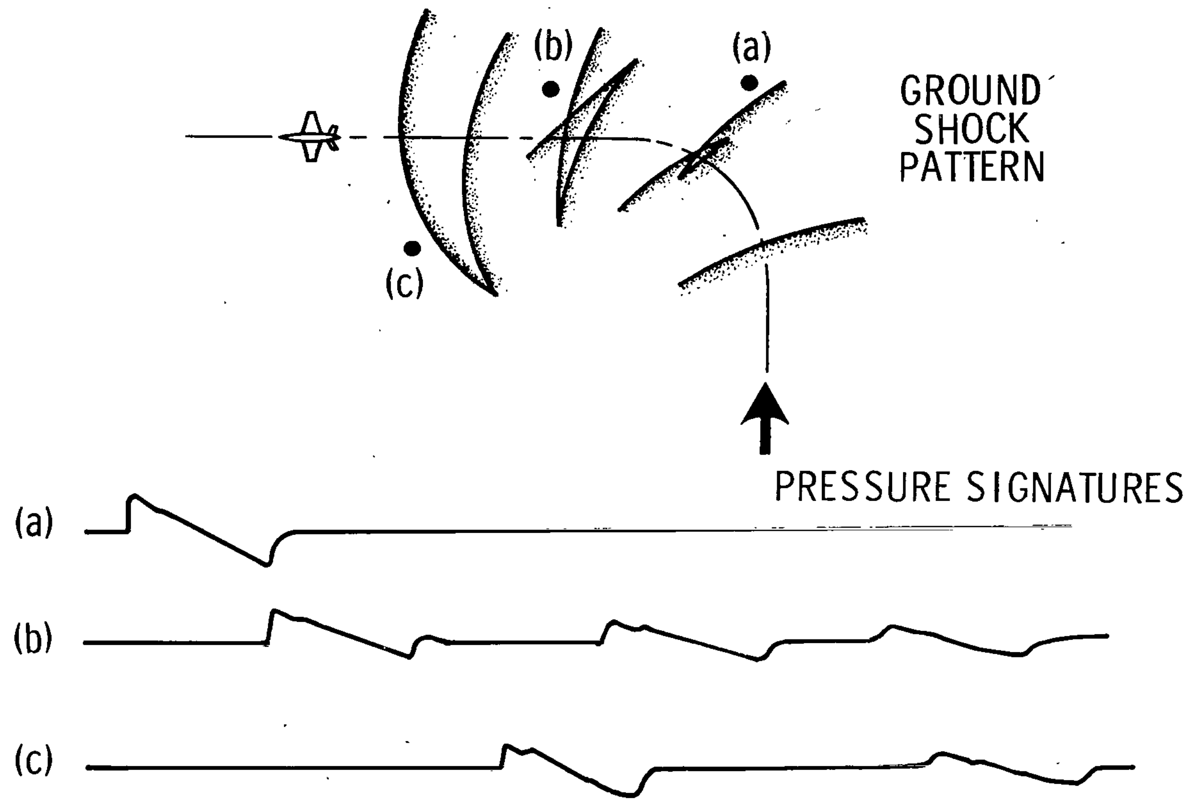

Figure 5.- Measured pressure signatures at three ground stations along with shock-wave schematic diagram for a 90° circular turn of the aircraft at constant Mach number of 1.5 and a constant altitude of 32,000 feet.

results obtained, sample ground-pressure time histories are presented at the bottom of the figure for measuring stations in the vicinity of points (a), (b), and (c), respectively.

A measurement at position (a) would produce a single N-wave pressure signature, whereas, at locations (b) and (c), two or three complete N-wave signatures might be recorded. Here again a definite progression of pattern development exists; however, the events do not necessarily occur in the same sequence of the previously discussed longitudinal-acceleration case. Because of the nature of the maneuver, the first measured pressure disturbance is not necessarily the maximum that will occur at any given measurement point.

It is believed that a superboom condition existed in the vicinity of the cusp formation; in fact, during one test a pressure buildup of about a factor of 4 was recorded.

A summary of the results obtained from a comparison of the experiment and theory is presented in the following table. Agreement was noted with regard to

TABLE I.- COMPARISON OF MEASURED AND CALCULATED SHOCK-WAVE GROUND-INTERSECTION PATTERNS ASSOCIATED WITH AIRCRAFT MANEUVERS

Number of booms	Longitudinal acceleration . . . . 2 to 4 Circular turn . . . . 2 to 6 Pushover . . . . 2 to 6
Overpressure buildup factor	Measured 2 to 4 No rigorous method for prediction Empirical method estimates approximately 3
Distance interval	Within 1,000 feet Predicted closer than measured
Initial superboom impact	Within ±2 miles

the number of sonic booms observed. For the longitudinal-acceleration case, 2 to 4 booms were observed whereas in circular-turn maneuvers and supersonic-pushover maneuvers, 2 to 6 booms were observed. The number of observed booms is a function of observer location. These results compare with the normally observed 2 booms (associated with the bow- and tail-shock waves) for steady flight. The pressure-buildup factor was measured to be from 2 to 4, whereas an empirical-estimation method predicted a factor of 3. Although some progress is being made in calculating the shock strength by using step-by-step nonlinear calculating procedures (ref. 7), no results from this method are currently available. The relative positions of the multiple shock waves observed during the measurements were noted to be within 1,000 feet of the predicted relative positions for the on-the-track locations. The location of the initial superboom impact was found to be predictable within about ±2 miles when good temperature profile and airplane position information were available.

CONCLUDING REMARKS

Superboom measurements and calculated pressure patterns have been made for fighter aircraft in level accelerated flight and in turn maneuvers. From 2 to 6 booms were observed (compared with the normally observed 2 booms for steady flight), and pressure-buildup factors of from 2 to 4 were measured (depending on the type of maneuver and the location of the observer). The relative positions of the multiple shocks and the location of the initial superboom impacts for specific cases were found to be predictable to within 1,000 feet and ±2 miles, respectively, when the temperature profiles and airplane position information were available. The experiments have, however, suggested the need for a more adequate analytical method of predicting the pressure buildups and for determining the effects of atmospheric anomalies on the ground intersection patterns.

Langley Research Center,
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